SATELLITE MONITORING OF SEA SURFACE POLLUTION

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16. Abstract

HCMM transparencies of the marine areas around the U.K. are still arriving at Lancaster and are being filed on magnetic tape according to date. A full search for polluted sea or coastal areas will commence soon. In an earlier search, only one anomaly was suspected to represent an oil slick. Image processing facilities involving a specially built grey level slicer, a videodensitometer, a microprocessor, and associated software and hard copy generators have all been tested. Position finding computer routines and map making methods have also been tested. Recovery of sea truth has been studied and applied to special cases of HCMM imagery. Experimental work on direct, and remote, temperature sensing of liquid systems has been developed to act as control on the detection of an oil film at sea: the infra-red characteristics of such a film differ from those of unpolluted water in ways that depend on environmental parameters such as wind speed, air temperature and humidity, the weather conditions at the time of the spill, and the interval between that time and the time of observation.

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Satellite Monitoring of Sea Surface Pollution

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Sponsoring Organisations: Department of Industry, London, and University of Lancaster, England.

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2-15/DF1-1 Objectives of Investigation

The overall aim of this research is to investigate the feasibility of the use of data drawn from the visible and near-IR (500 to 1100 nm) and from the thermal-IR (10500 to 12500 nm) bands of NASA's Heat Capacity Mapping Mission (Explorer-A) satellite, as applied to the sea surfaces centring on the North Sea, to study marine pollutants, particularly oil. The area under investigation is defined in Fig. 1.

2-15/DF1-2 Scope of Work

The research divides broadly between the analysis of HCMM satellite imagery of the marine areas around the U.K. and experimental work designed to provide some of the insight needed in the detection of oil spills at sea using the HCMM, or similar, imagery.

The need for analysis of the visible and IR imagery on the synoptic scale led to the development of false colour image processing techniques. The needs of small scale surveys of particular images led us to develop density slicing, and other high resolution image analysis, techniques. The availability, nature, and speed of recovery of existing sea truth was investigated. Methods of filing and of recovery of the incoming satellite pictures were developed.

Outdoor and indoor simulators were used to study the differences in the thermal regimes between systems consisting of uncontaminated water, on the one hand, and water contaminated with oil, on the other. The effects of ambient temperature, humidity and air velocity on the simulator systems were studied.

Fig. 1

The quadrangle which limits the
area of the present investigation.

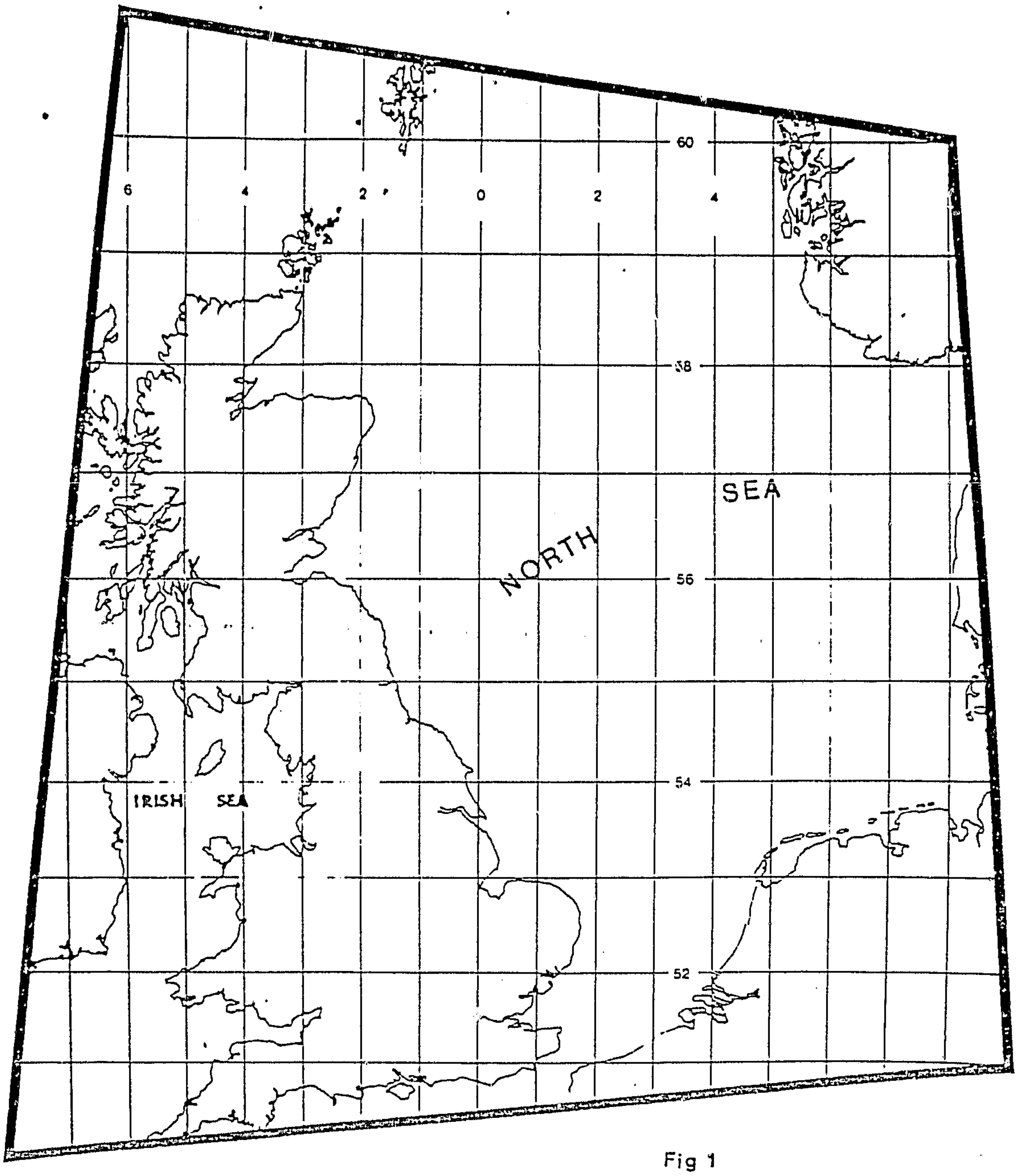


Fig 1

2-15/DF1-3 <u>Outline of Preliminary Conclusions</u>

Since photographic data from the HCMM mission are still being catalogued, a full analysis of the data has not been attempted and further conclusions (see 2-14/P6-16) relating to the detection of oil spills on the imagery must be deferred until the Final Report.

Video processing techniques appropriate to the semi-quantitative analysis of the HCMM imagery were successfully developed by D. J. Telfer (2-13/P5-3), who also developed accurate methods of quantitative video line processing using at PET microprocessor and floppy disc system.

Computer programmes for mapping the positions of features at sea in relation to coast lines visible in the imagery were prepared by R. J. Fryer (1-04/P2-6). Software for operating the associated I/D position location pad was written by D. J. Telfer.

Investigations of available sea truth for given dates of interest led to the conclusion that useful correlative work between measurements of the appropriate physical parameters at the sea surface and records prepared from HCMM data will be achieved only after specially instrumented and specially distributed data collection devices become operational.

Controlled experiments on artificial oil slicks in the laboratory environment and in direct sunlight outside have led to a number of important conclusions having direct relevance to the detection and monitoring of oil at sea by satellite. Even if oil is spilled at the same temperature as that of the sea water the oil slick rapidly acquires a different surface temperature; and the thermal regime of an oil-on-water system differs from that of an all-water system. The temperature, and surface property, differences between the two systems lead to ready detection of oil (within the resolution capability of the sensors) in the infra-red waveband. However, the problem is complicated by the fact that the oily surface may appear warmer, or cooler, than the surrounding sea surface; and it follows that under special (rare) circumstances, the two surfaces might be indistinguishable in so far as temperature is concerned. Prediction as to whether a particular oil spill at a specified instant of time will appear warm or cool in relation to the uncontaminated water around the spill can be accurate, in general, only if certain environmental parameters pertaining to the region can be provided, together with information about the spill itself. Thus, although the problem of monitoring oil spills in the infra-red is not simple, headway has been made in understanding the intricacies of the problem. (Please see present report, 2-15/DF1-9 and 10).

2-15/DF1-4 Personnel

G. Fielder acted principally as project manager, D. J. Telfer principally as operator through Phase 1 (pre-launch) and until 14th April, 1980 in Phase 2, when he resigned as Co-Investigator and became Consultant to facilitate the transition of the co-investigatorship to T. S. Hall, who took up the appointment on 13th May, 1980. R. J. Fryer acted as Consultant in the preparation of computerised cartographic routines, and L. Wilson as Consultant on the handling and reading of the HCMM CCT's supplied by NASA, as well as on computer matters generally. Miss S. Stackhouse assisted with the cataloguing of HCMM photographs.

2-15/DF1-5 Satellite Data

NASA designated 30th March 1979 as the official date of first receipt of HCMM data by investigators. A total of 2032 transparencies covering marine areas around the U.K. have now been received. The transparencies were sent first to London via diplomatic bag from the U.S.A. There is no evidence that our receipts of HCMM standard data products have ceased, yet: the latest batch arrived on 14th July 1980. These data have been coded and catalogued manually while the bulk of the data has been entered on magnetic tape for rapid retrieval of transparencies relating to a given date and time. A final search for oil slicks will be made only when the magnetic tape inventory is complete. Hence the present report cannot in any way be regarded as assuming the format of a Final Report.

In addition to all these transparencies, a total of 813 photographic scenes of the Western European area have arrived from the Lannion Centre for Space Meteorology, France. These have also been catalogued manually and they have also been recorded on magnetic tape.

Eight, 1600 b.p.i. CCT's were ordered on 25th June, 1980 to replace those 800 b.p.i. CCT's sent erroneously by NASA in responses to our earlier orders.

2-15/DF1-6 Sea Truth

The principal source of sea truth lies in the Department METO 12c of the Meteorological Office at Bracknell, England. The number of sea surface points at which data have been measured within the bounds of an area recorded in an HCMM image is small. The number reduces even further when parameters such as wind vector are required as well as temperature. On a completely clear day or night the HCMM thermal channel provides a much better picture of the distribution of sea surface thermal anomalies that that provided by all the in situ measurements in the seas around the U.K. When

tight control of measured sea surface temperatures is available, it is generally pertaining to too small an area to be of general use in the calibration of HCMM images.

A plan to use sea truth relating to controlled releases of oil on the sea by the Warren Spring Laboratory of the Department of Industry, in order to calibrate HCMM images, was discarded when it was established that a volume of oil some two orders of magnitude greater than that permitted in the Warren Spring programme would be required were such a slick to be detected using the HCMM satellite.

2-15/DF1-7 Reported Oil Slicks

Information on oil spills received from the Department of Trade, London, commonly includes the estimated location of the oil and the length of the slick. The principal input derives from U.K. Coastguards; although we have also searched the appropriate "Oil Spill Intelligence Reports" published at Boston, Mass.

The most significant of the spill data have been abstracted on a card index and the longest spills, or those having the greatest size, have been isolated as a basis for searching for anomalies on any corresponding HCMM imagery.

2-15/DF1-8 Summary of Methodology used in Performing the Investigation

The laboratory methods used in the present investigation include colour video slicing, videodensitometric profiling, picture digitisation analysis, oil slick simulation under conditions of controlled temperature and humidity, computer modelling of the thermal regime of simple slicks, and oil slick simulation under controlled, windy conditions using a wind tunnel. In addition, an outdoor oil slick simulator has been used to study the thermal effects of oil-on-water when solar radiation falls upon the system. Work already done (2-14/P6-5) will be presented in the Final Report; while fresh results obtained using the outdoor simulator and wind tunnel will be described here.

2-15/DF1-9 Use of Outdoor Simulator

This system was described in 2-14/P6-5, where it was shown that, in sunny conditions, the oil film covering a tank of water presented a temperature that was significantly higher that that of the surface of the all-water system in an identical, adjacent tank. In that preliminary experiment, temperatures in the surface and bulk layers were monitored directly using PRT sensors.

Additional experiments have now been completed employing remote sensing techniques in the visible and IR, in order to approach the type of sensing system incorporated in the HCMM

satellite. The gantry of the simulator carried two 35 mm Zenith reflex cameras, one loaded with a panchromatic film and one with a film sensitised to respond principally over the 670-880 nm waveband. The gantry also carried an Eltec IR sensor and chopper unit with cables leading to a phase-sensitive detector (PSD) housed in a nearby laboratory.

Crude oil from the Ekofisk platform of Norpipe Petroleum Limited (U.K.) was introduced to the surface of one of the tanks of water after both tanksful had been left long enough to ensure that a condition of mutual equality of bulk water temperature pertained. The gantry carrying the sensors was rotated in 15 degree increments of elevation and, after each increment, IR readings (measured in millivolts) were taken from the gauge of the PSD and, at the same time, control photographs were secured using remote control shutter release pneumatic lines. For each elevation of the gantry the tanks were observed in rapid sequence, by sliding the sensor carriage along the horizontal track of the gantry, in order to achieve equality, or near equality, of environmental factors such as solar altitude and atmospheric extinction.

These experiments tended to confirm those using PRT sensors, in that the oil surface was generally warmer than the unpolluted water surface (See Appendix A). Moreover, it was noticed that, whenever the wind over the tanks increased (even in short gusts), the PSD registered changes which indicated that the temperature of the oil surface increased even more above that of the water surface.

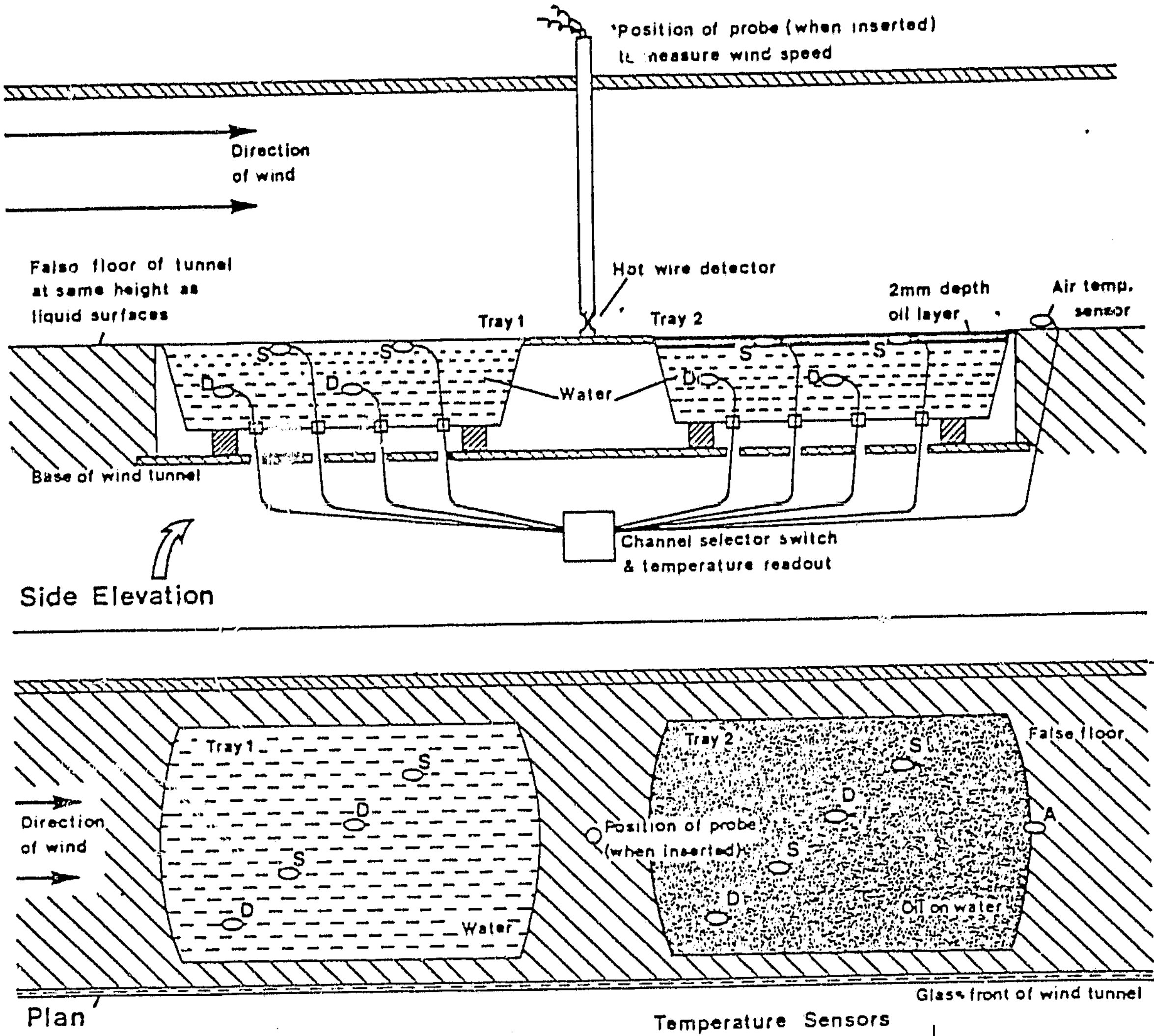
2-15/DF1-10 Use of Wind Tunnel

In order to investigate this effect, a low velocity wind tunnel with a working section of about 625 cm^2 was adapted to our needs by removing part of the false floor and lowering two, adjacent plastic trays into the cavity in such a way that their rims were level with those parts of the false floor which were left, in situ, both immediately upstream, and immediately downstream, of the trays.

Four circular apertures were cut in the base of each of the plastic trays and each aperture was filled and sealed with a rubber bung carrying the leads of a platinum resistance thermometer probe which entered one of the plastic trays (Fig. 2). The PRT leads were fed through holes, drilled in the base of the wind tunnel and corresponding to the apertures in which the bungs were inserted, to the 4-digit Farnell temperature recorder and channel selector described in 2-14/P6-5 and illustrated diagramatically in Fig. 4 of that report. Each tray was filled to the brim with a measured volume (3.0 ℓ) of tap water and allowed to attain thermal equilibrium.

Fig. 2

Diagrammatic representation of oil slick simulation in a wind tunnel, showing location of the nine temperature sensors



(Not to scale)

Temperature Sensors
D Sensor in bulk of water
S Sensor in surface of water or oil
A Sensor in air boundary layer

Fig 2

Two temperature sensor elements were arranged to lie just in the upper 2 mm of liquid in each reservoir and two in the bulk of the liquid (water) in each reservoir. These sensors were offset from the longitudinal axis of the wind tunnel by amounts which minimised the effect of the presence of one probe on the reading of another probe. A ninth temperature sensor was used to measure air temperature in the boundary layer immediately downstream of the tanks (Fig. 2).

The fan of the wind tunnel was fed from the mains through a Foster Voltage Regulator which was calibrated in terms of wind speed using a ETA 3000 hot wire anemometer manufactured by Airflow Developments Ltd. Wind speeds of from 0.5 to 10 m s^{-1} were generated just above the surfaces of the fluids in the tanks: this range embraced the critical value of wind speed at which we predicted a transition from laminar to turbulent flow (2-14/P6-5). In practice, the upper limit of wind speed was 8 m s^{-1}, since above this value the water tended to spill over the leeward edge of its container.

A volume of 125 ml of water was removed from one of the trays and the same volume of crude oil added, by pipette, in order to produce an oil layer exactly 2.0 mm thick: this was also the diameter of one of the cylindrical PRT sensors. For pre-selected wind speeds (Figs. 3 and 4) the temperatures measured by the nine sensors were then read at given time intervals over a period long enough to determine the approach of each of the two systems to equilibrium.

With the room temperature slightly higher than that of the fluids, tests showed that the oil surface gained heat relative to the unpolluted water surface. This effect increased with increase of wind velocity. The temperature of the air in the wind tunnel relative to the temperature of the water was then increased further, in an attempt to exaggerate the effect already noted, by introducing an electric heater at the air intake end of the tunnel. The general results of these tests, considered to be simulating conditions similar to those applying to the North Sea in summer, are tabulated in Appendix B and are shown graphically in Fig. 3 (for a low wind speed) and Fig. 4 (for a "high" wind speed).

Preliminary tests designed to simulate winter conditions have already been run in the same wind tunnel. Apart from the practical importance of these results in the study of summer/winter differences in the thermal signature of oil spilled in our marine areas, these results together with our earlier (2-14/P6-5) results also have a bearing on the problem of satellite location and monitoring of oil slicks near shorelines where sea breezes or land breezes can alter the temperature and humidity of the air passing over a polluted sea zone.

Fig. 3

Graphs illustrating how, in summer conditions, the temperature of an oil slick asymptotes at a higher level than the temperature of uncontaminated water under similar environmental conditions with a wind blowing at 1 m s^{-1}

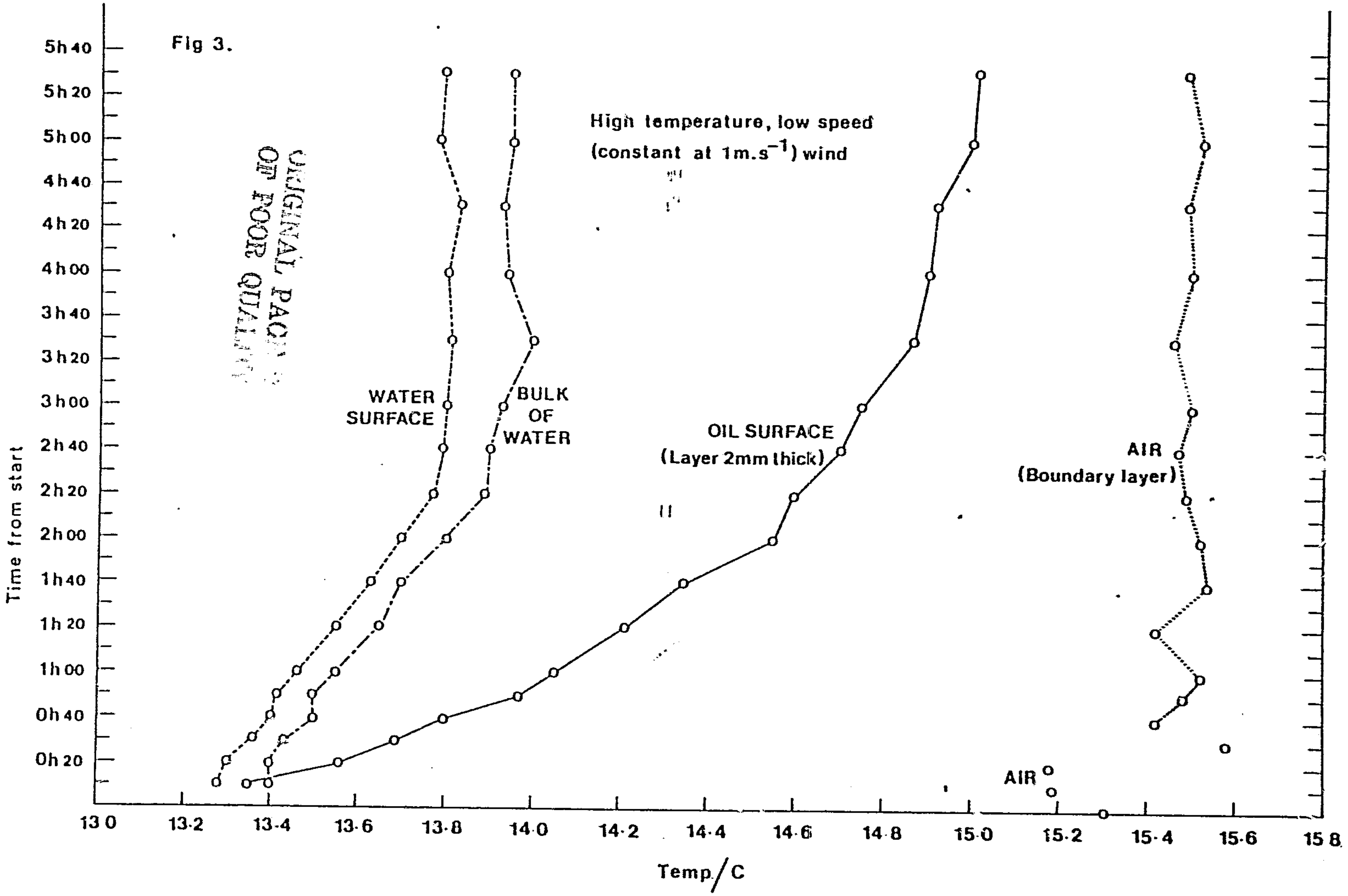
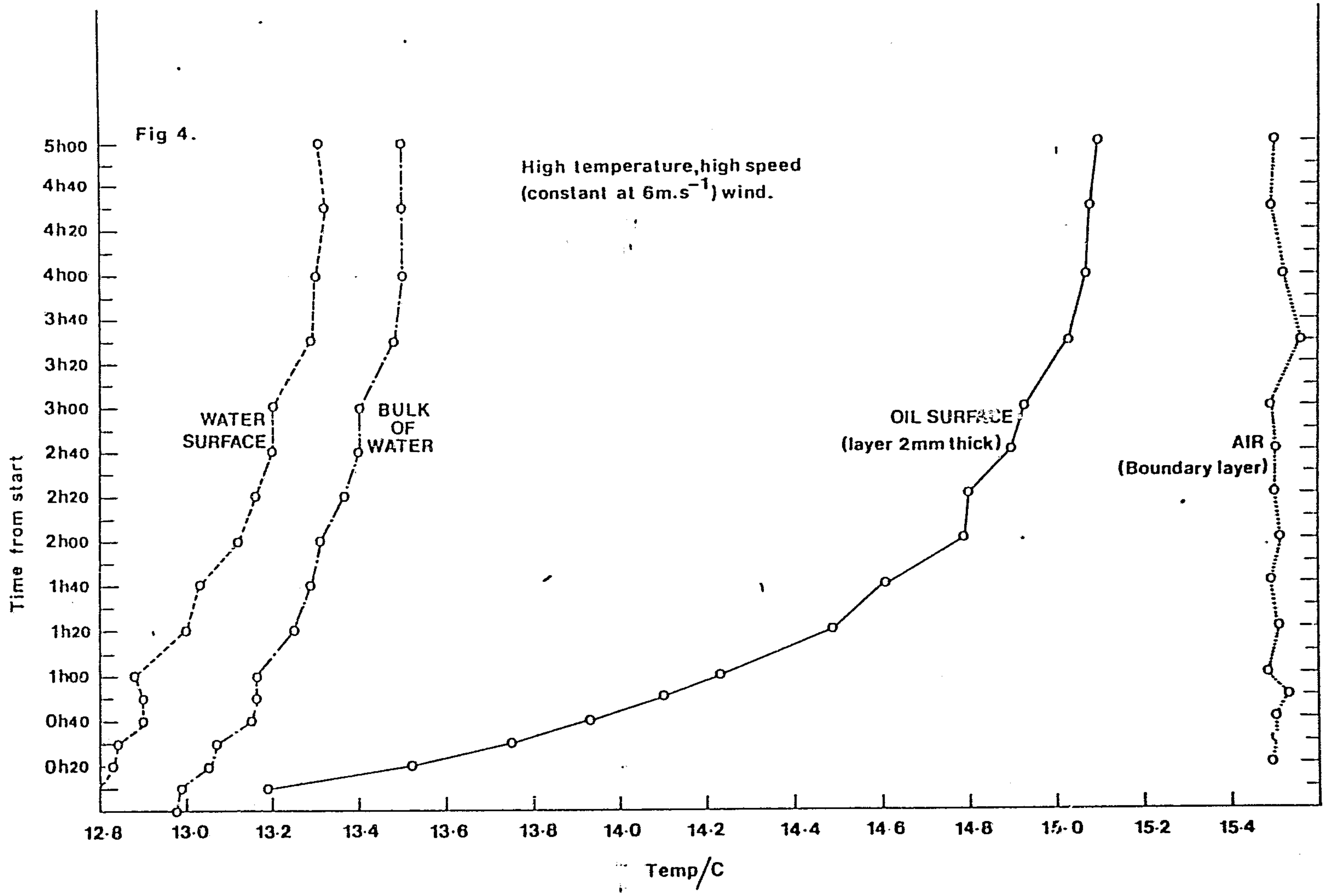


Fig 3.
High temperature, low speed
(constant at 1m.s^{-1}) wind
WATER SURFACE
BULK OF WATER
OIL SURFACE
(Layer 2mm thick)
AIR
(Boundary layer)
AIR
Time from start
5h40
5h20
5h00
4h40
4h20
4h00
3h40
3h20
3h00
2h40
2h20
2h00
1h40
1h20
1h00
0h40
0h20
13.0
13.2
13.4
13.6
13.8
14.0
14.2
14.4
14.6
14.8
15.0
15.2
15.4
15.6
15.8
Temp/C

Fig. 4

Graphs illustrating how, in summer conditions, the temperature of an oil slick asymptotes at a still higher level (cf. Fig. 3) than the temperature of uncontaminated water under similar environmental conditions with a wind blowing at 6 m s^{-1}

Fig 4.


High temperature, high speed
(constant at 6m.s^{-1}) wind.
WATER SURFACE
BULK OF WATER
OIL SURFACE
(layer 2mm thick)
AIR
(Boundary layer)
Time from start
5h00
4h40
4h20
4h00
3h40
3h20
3h00
2h40
2h20
2h00
1h40
1h20
1h00
0h40
0h20
12·8
13·0
13·2
13·4
13·6
13·8
14·0
14·2
14·4
14·6
14·8
15·0
15·2
15·4
Temp/C

12B

2-15/DF1-11 Quality of Data Products

In any future experiments, attempts should be made to improve the quality of data products. Whereas we are not yet in a position to comment on the quality of the CCT's, we have been disturbed by the appearance of spurious herring bone patterns in the IR imagery. These patterns, found on many occasions, were found to have a wavelength of the order of a few pixels and were generally accompanied by a grainy texture in addition to the spurious intensity modulations of the raster lines. This last mentioned defect is a consistent feature of the IR imagery.

2-15/DF1-12 Realistic Assessment of Oil Detection Problem

The resolution offered by the HCMM system needs to be drastically improved if advantage is to be taken of a satellite surveillance system in the thermal IR. This might be achieved through the use of IR radiometers having improved aperture characteristics. This need follows from the fact that, most commonly, the image events being investigated are of the order of only a few pixels, or less, in size. The problems associated with the investigation of small size events have been exemplified in the report (2-14/P6) of the Anglesey spill.

The temperature resolution of the HCMM system, as investigated using our video system, appears to be adequate, whereas further interpretation requires concomitant spacial resolution if the extraction of reliable information is to become possible for small events.

The well known cloud cover problem necessitates the parallel use of a large microwave radiometer system. The desired results might be achieved only when facilities are available to place much larger microwave radiometric installations in orbit than are in use currently. In the case of both IR and microwave carrying satellites, a fully operational system of oil slick/pollutant detection would need to involve a higher rate of satellite overpass than that enjoyed by the HCMM satellite, and this could be achieved through the use of a multi-satellite system. The present system is working on the edge of the expectancy threshold for pollutant detection.

2-15/DF1-13 Format of Final Report

After the cover and title pages, the Final Report of this project will have a Preface containing a statement of objective, a description of the scope of the work, a set of conclusions and a summary of recommendations. The Preface will be followed by a Table of Contents page, listing the principal headings and page numbers, a List of Illustrations with identification numbers, captions and page numbers, and a List of Tables with numbers, titles and page identifications.

The main Text of the report will provide an overview of the technical history of the project, and a description of the systems, subsystems and components used to complete the project. In addition, significant scientific and technical developments, theories, procedures, techniques, tests and results will be set down.

Appendices labelled "A", "B", etc., List of References and an Index will complete the Final Report.

Appendix A - Specimen of Outdoor Simulator Results

Altitude of Sun: 57°

Elevation/°		Readings on PSD/mV		Difference/mV
		sensor above water	sensor above oil	
NW	30	1.51	1.84	0.33
NW	45	1.72	2.18	0.46
NW	60	1.47	2.07	0.60
NW	75	1.20	1.80	0.60
	90	0.97	1.64	0.67
SE	75	0.90	1.67	0.77
SE	60	1.10	2.11	1.01
SE	45	1.42	2.65	1.23
SE	30	1.89	2.95	1.06

Larger PSD readings correspond to higher temperatures.

Appendix B - Wind Tunnel Results: "Summer" Conditions

Wind velocity m s^{-1}	Time after oil spillage	Water surface temp/C	Oil surface temp/C	Tunnel air temp/C
	h m			
1.0	10	13.28	13.35	15.2
	20	13.30	13.56	15.2
	30	13.36	13.69	15.6
	40	13.40	13.80	15.4
	50	13.41	13.97	15.5
	1 00	13.46	14.05	15.5
	1 20	13.55	14.21	15.4
	1 40	13.63	14.35	15.5
	2 00	13.70	14.55	15.5
	2 20	13.77	14.60	15.5
	2 40	13.79	14.70	15.5
	3 00	13.80	14.75	15.5
	3 30	13.81	14.87	15.5
	4 00	13.80	14.90	15.5
	4 30	13.83	14.92	15.5
	5 00	13.78	15.00	15.5
	5 30	13.79	15.01	15.5
6.0	10	12.79	13.19	15.4
	20	12.83	13.52	15.5
	30	12.84	13.75	15.5
	40	12.90	13.93	15.5
	50	12.90	14.10	15.5
	1 00	12.88	14.23	15.5
	1 20	13.00	14.49	15.5
	1 40	13.03	14.61	15.5
	2 00	13.12	14.79	15.5
	2 20	13.16	14.80	15.5
	2 40	13.20	14.90	15.5
	3 00	13.20	14.93	15.5
	3 30	13.29	15.03	15.6
	4 00	13.30	15.07	15.5
	4 30	13.32	15.08	15.5
	5 00	13.31	15.10	15.5